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Pavement Management System for Rigid Pavement Using CPR Techniques

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Abstract: The need for engineered rehabilitation of our transportation infrastructure has never been greater. There is increasing demand to make better use of shrinking resources for rehabilitation and maintenance of our highways and city streets. There are a number of concrete pavement restoration, resurfacing and reconstruction techniques, also known as CPR3 (R3 stands for restoration, resurfacing and reconstruction), to address the various distresses in the concrete pavements. Selecting the most cost-effective CPR3 requires the transportation professionals to have knowledge of the various concrete pavement restoration techniques. This study focuses on the many restoration techniques available to extend the concrete pavements life including: full-depth/partial depth repairs, joint and crack resealing, slab stabilization/Jacking, diamond grinding, load transfer restoration, and cross-stitching longitudinal cracks. These concrete pavement restoration (CPR) techniques will prolong and enhance the concrete pavement's service life in a cost-effective manner. A pavement design engineer can easily adopt the proper CPR technique based on the local materials, environmental conditions, project distress conditions and costs. This study focuses on providing a suitable solution on the basis of field data that we have collected from field and a program is made in Microsoft Excel using VBA language to provide best solution for concrete pavements rehabilitation techniques

Keywords: **Pavement Restoration Techniques, CPR Techniques, Pavement Management, Pavement Maintenance, Rigid pavement**.

Abbreviations and Acronyms:

CPR- Concrete Pavement Rehabilitation
CPR3- Where R3 stands for Restoration Resurfacing and Reconstruction
CBR- California Bearing Ratio.
Mpa- Mega Pascal
VBA- Visual Basic for Applications
LHS- Left Hand Side
RHS- Right Hand Side
PQC- Pavement Quality Concrete
GSB-Granular Sub Base
DLC-Dry Lean Concrete
MDD-Maximum Dry Density

I. INTRODUCTION

Concrete pavements are mostly used in India due to higher axle loads and increasing in traffic volumes. Concrete is used in roads, highways and airport pavements because of its load carrying capacity and low maintenance. Pavements and their underlying support layers are a complex, interdependent system. The performance of this system is influenced significantly by traffic loading, climatic conditions, maintenance practices, the original design, and the construction of the pavement structure, foundation layers, and drainage system. Over the life of a concrete pavement, distresses can occur—and, in most cases, the distresses can be attributed to multiple causes. The distresses do indicate the failure of concrete slabs but more than that they indicate the human failure to understand the few basic and fundamental things related to concrete material and pavement. Accurately identifying the distress, understanding the cause(s) of the distress and how to prevent it on future projects, and determining the proper repair procedures can be complicated. Historically, distresses in concrete pavements have been identified largely through visual surveys with limited investigation into the underlying cause(s) of the distress, and often with limited knowledge of how to cost-effectively maintain a concrete pavement in good condition. The repair and restoration of concrete pavement depends on the type of distress.

This study examines the distress classification, different repair& restoration techniques of concrete pavement. This paper also provides a solution on the basis of data collected through making a program in Microsoft Excel using VBA language which can give solution for rehabilitation of concrete pavements.
The study is conducted on Manoharpur- Dausa section of NH-11A (New NH-148) (Rajasthan, India) which is being widened to Two Lane with paved shoulders from the existing two lanes.

II. LITERATURE REVIEW

- **Leite-Gembus Fabiana, Thomson Graham et. al (2017)**in this study, the positive performance of a concrete pavement rehabilitation in the southeast of Brazil with the reinforcement. The high-traffic highway MG-424 was severely cracked and damaged after an unsuccessful asphalt resurfacing. Crack Activity Meter (displacement measurement device) was used to evaluate the pavement conditions and to adopt a proper rehabilitation structure. The vertical and horizontal movements between the expansion joints and large cracks were measured and analysed in terms of Load Transfer Efficiency. Based on the deflection results and on the observed performance, it is possible to conclude that the asphalt reinforcement is an effective treatment against reflective cracking in asphalt overlays, contributing to an extension of pavement service life.
- **Fung Rico Et.al (2010)**This study focuses on the available restoration techniques which was used to extend the life of concrete pavements such as full-depth/partial depth repairs, joint and crack resealing, slab stabilization/Jacking, diamond grinding, load transfer restoration, and cross-stitching longitudinal cracks. All the above-mentioned concrete pavement restoration (CPR) techniques will increase and enhance the concrete pavement's service life in a cost-effective manner. A pavement design engineer can easily adopt the proper CPR technique based on the local materials, environmental conditions, project distress conditions and costs.
- **Pan Youqiang and Guo Zhongyin (2009)** This paper summarizes and presents a comparison through physical form analysis and indoor tests of three kinds of concrete deck treatment: manual work treatment, milling treatment and sandblast treatment. The test results show that milling treatment can improve shear performance more than sandblast treatment. This paper suggests a more reliable way to improve the shear performance of concrete deck pavement..
- **Ryu Sung Woo et.al(2009)**A thin-bonded CRCO (Continuously Reinforced Concrete Overlay) on a JCO (Jointed Concrete Overlay) was constructed at Seo Hae Ahn Express Highway in Korea. This project includes two experimental sections: 1) a JCO with saw-cut joints over existing transverse joints, and 2) a CRCO, which employs transverse and longitudinal steel reinforcing rods, that is placed on top of an existing JCO. After milling 5 cm off the top of the JCO, an overlay thickness of 10 cm remains. Several VWSGs (Vibrating Wire Strain Gauges) were installed to evaluate curling, delamination behavior, and crack propagation of the thin-bonded CRCO. This paper describes the early behavior of this overlay and compares the current and new rehabilitation methods available in Korea.
- **Lee Eul-Bum, Choi Kunhee(2006)** This case study presents an innovative fast-track reconstruction approach applied to a heavily trafficked Long-Life (30-plus years) Pavement Rehabilitation Strategies project on I-15 in Devore in Southern California. A 4.5-km stretch of badly damaged concrete truck lanes was rebuilt over two 215-h (approximately 9-day) periods with one-roadbed full closures with counterflow traffic and around-the-clock (24 h per day/7 days per week) construction operations. The same project would have taken 10 months to complete with traditional nighttime closures. State-of-practice technologies were adopted on this Rapid Rehab project to accelerate construction, mitigate traffic disruptions, and propagate project information. From the initial planning and design stages, engineers used CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) software incorporated with traffic simulation models to develop an optimal and economical rehabilitation scenario.
- help of a high modulus polyester grid as asphalt

III. METHODOLOGY

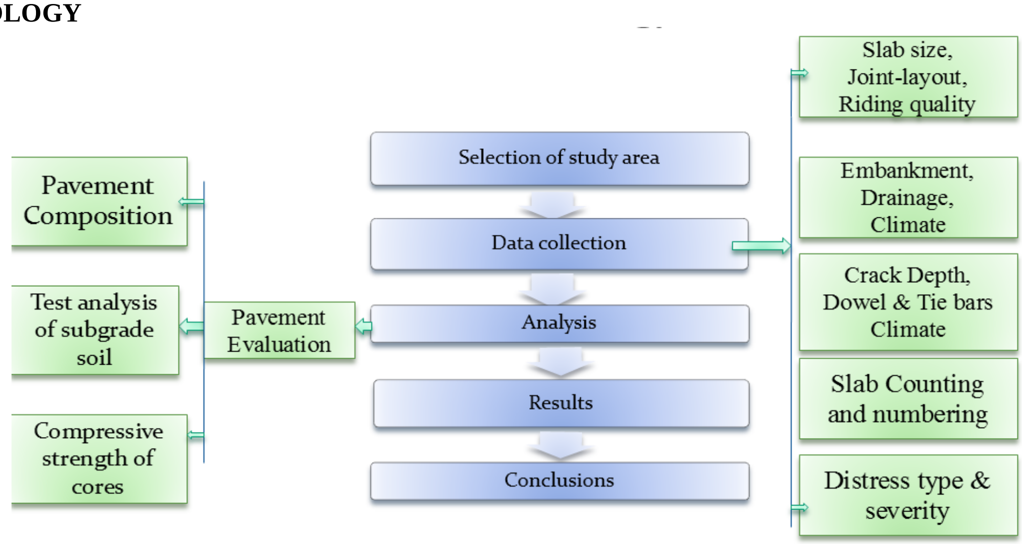

Figure 3.1: Flowchart representing the methodology adopted for the study

IV. DATA COLLECTION

- Slab Counting and Numbering: Slab counting and numbering was done the numbering on site was done in the direction opposite to the direction of travel. Also, the numbering from RHS began from where the numbering on LHS had ended.
- Slab Size: Slab size of the section was noted, The slab width varies from 3.5 m to 7 m. Length of the slab generally varies between 4.3 to 4.5 m.
- Joint layout: Joint Layout was carefully recorded, Transverse joints are present in the entire length of the pavement and Longitudinal joints are not present continuously
- Riding Quality: Roughness was not measured with any equipment, but the riding quality is generally good to fair.
- Embankment: The entire 1.3 km section of rigid pavement is at ground level.
- Drainage: There are no side drains provided drains along the rigid pavement section
- Climate: The rainfall in the area is low. Summer temperature varies between 30 to 41° C while winter temperature varies between 15-25° C
- Crack Depth: Coring was done at six locations to measure depth of the crack, that the cracks extended beyond the mid-depth of the slab
- Dowel and Tie Bars: Slabs were broken to find the data related to dowel and tie bars.
- Determining Distress Type and Severity: Rating of the distress was done as per the severity levels defined by IRC: SP: 83-2008

Table 4.1: Summary of Distress in LHS

LHS			
Type of Cracking	**Total Number of Slabs**	**Severity 2,3**	**Severity 4,5**
Longitudinal	137	100	37
Transverse	132	67	65
Multiple	45	-	45

Table 4.2: Summary of Distress in RHS

LHS			
Type of Cracking	**Total Number of Slabs**	**Severity 2,3**	**Severity 4,5**
Longitudinal	141	42	99
Transverse	68	43	25
Multiple	74	-	74

V. RESULTS & ANALYSIS

- In the analysis complete payment evaluation was done
- Test pits were dug at 8 locations to measure the thickness of pavement layers and determine the properties of the subgrade soil

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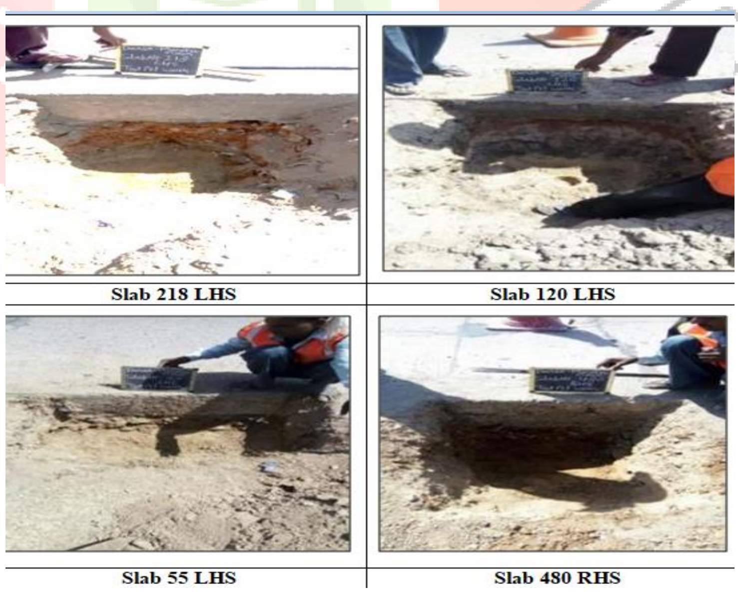

Figure 5.1: Photos of test pit

- Pavement composition was also analysed with the help of test pits and the composition was as follows

Table 5.1: Composition of existing pavement

S. No.	Slab No.	Side	PQC (mm)	GSB (mm)	Total (mm)
1	338	RHS	300	210	510
2	480	RHS	300	240	540
3	55	LHS	300	260	560
4	218	LHS	330	230	560
5	120	LHS	300	250	550
6	364	RHS	310	220	530
7	423	RHS	300	210	510
8	168	LHS	300	200	500

- Sub grade soil was tested for various characteristics. Various laboratory tests were conducted including grading of soil, Modified Proctar Test.
- Test results show that the sub grade soil is sandy to silty with minor to significant percentages of clay.
- The soil in LHS is mainly silt while in RHS it is mainly sandy. CBR is extremely low, of the order 2%, for soils that are clayey silt. At other locations, it varies from 5% to 15% for silty gravels/sands.
- The compaction level of existing subgrade varies from 84 to 100% in LHS while in RHS it varies from 86 to 93%.

Table 5.2: Laboratory Test Results of Existing Subgrade Soil

S. No.	Slab No. Marked on Site (Slab no as per condition survey in LHS)	Side	Soil Description	IS Classification	Gradation: Percent by weight retained on the Sieve (IS:2720-IV)						Clay & silt content %	Atterberg Limits [IS :2720-Pt-V]					Modified Proctor Test (IS:2720-Pt-VIII)		Compaction level (%)	4-day soaked CBR at 97% MDD (%)
					19 mm	10 mm	4.75 mm	2.0 mm	425 micron	75 micron		LL %	PL%	PI %	FMC %	FDD gm/cc	MDD gm/cc	OMC %		
1	55 (198)	LHS	Clayey Silt of Medium Plasticity	CI	0.00	0.00	6.25	5.10	7.85	6.80	74.0	35	19	16	10.54	1.86	1.86	13.0	100	2.04
2	120 (133)	LHS	Silty Sand with Clay	SM-SC	0.00	6.00	11.2	9.80	12.3	24.4	36.3	26	20	6	4.97	1.73	2.03	9.0	85	9.30
3	168 (85)	LHS	Silty Gravels	GM	0.00	21.30	24.4	12.8	13.30	17.30	10.9	24	NIL	NP	4.53	1.62	2.03	9.0	80	15.12
4	218 (35)	LHS	Silty Sand	SM	8.20	0.60	2.80	2.30	3.70	75.20	7.20	-	NIL	NP	4.67	1.54	1.84	10.0	84	6.40
5	338	RHS	Clayey Sand	SC	0.00	1.50	8.20	2.90	7.00	37.10	43.3	29	19	10	7.39	1.59	1.86	11.0	86	5.52
6	364	RHS	Silty Sand with Clay	SM-SC	0.00	15.60	6.90	6.00	6.00	22.40	43.1	27	20	7	9.97	1.86	2.01	9.5	92	9.88
7	423	RHS	Clayey Silt of Medium Plasticity	CI	0.00	0.00	0.50	0.30	1.50	16.80	80.9	37	23	14	9.11	1.78	1.90	12.0	94	1.74
8	480	RHS	Silty Sand	SM	0.00	0.00	0.50	0.00	0.90	64.50	34.1	-	NIL	NP	6.57	1.72	1.85	11.0	93	5.52

- Compressive strength of cores was calculated in laboratory
- Cores were cut in 20 slabs on both sides and taken to the laboratory for compressive strength testing. The results show that the compressive strength is between 23 to 38

Table 5.3: Results of Compressive Strength Testing on Cores

S.No.	Slab No.	Side	Dia (mm)	Height (mm)	Area (mm^2)	Weight (gm)	Load (KN)	Compressive Strength (MPa)	Correction Factor H/D	Corrected Compressive Strength (MPa)	Equivalent Cube Compressive Strength (N/mm^2)	Compressive Strength (MPa)
1	34	LHS	99.84	114.29	7828.87	1972	227.5	29.06	0.906	26.33	32.91	32.95
2	55	LHS	99.93	114.83	7842.99	1791	161.9	20.64	0.906	18.71	23.39	23.44
3	82	LHS	92.80	117.97	6763.72	1877	168.8	24.96	0.920	22.96	28.70	28.73
4	108	LHS	92.74	112.55	6754.98	1804	168.6	24.96	0.913	22.80	28.50	28.54
5	131	LHS	92.55	114.68	6727.33	1846	137.3	20.41	0.916	18.70	23.38	23.34
6	139	LHS	92.45	112.65	6712.80	1793	139.7	20.81	0.914	19.02	23.78	23.83
7	165	LHS	92.34	112.03	6696.84	1791	161.9	24.18	0.913	22.09	27.61	27.65
8	188	LHS	92.08	116.12	6659.18	1849	156.3	23.47	0.919	21.56	26.95	26.97
9	208	LHS	92.25	112.38	6683.79	1786	178.7	26.74	0.914	24.44	30.55	30.60
10	239	LHS	99.64	104.76	7797.53	1897	253.4	32.50	0.896	29.11	36.39	36.38
11	274	RHS	99.50	118.55	7775.64	1938	183.3	23.57	0.911	21.47	26.84	26.87
12	294	RHS	93.25	112.02	6829.48	1806	166.6	24.39	0.912	22.25	27.81	27.85
13	313	RHS	93.15	117.75	6814.84	1896	183.1	26.87	0.919	24.69	30.86	30.89
14	336	RHS	93.25	117.40	6829.48	1899	185.8	27.21	0.918	24.99	31.24	31.28
15	364	RHS	93.35	113.75	6844.13	1851	226.3	33.06	0.914	30.22	37.78	37.76
16	389	RHS	93.30	112.70	6836.80	1809	155.4	22.73	0.913	20.75	25.94	25.99
17	423	RHS	93.22	111.45	6825.09	1823	195.2	28.60	0.912	26.07	32.59	32.56
18	449	RHS	93.03	104.55	6797.29	1696	200.4	29.48	0.904	26.64	33.30	33.34
19	480	RHS	92.40	118.15	6705.54	1886	165.2	24.64	0.921	22.68	28.35	28.34
20	504	RHS	92.58	114.10	6731.69	1841	156.0	23.17	0.916	21.21	26.51	26.47

VI. CONCLUSIONS

- Almost the entire length of rigid pavement is distressed, irrespective of the subgrade type and condition
- Majority of the slabs have more than one crack i.e. a combination of 2 or more longitudinal cracks or longitudinal & transverse cracks or multiple cracks etc.
- Large number low severity cracks have also occurred on the pavement.
- Cracking has occurred despite the slab thickness being 300 mm and more.
- Longitudinal joints provided are intermittent and not continuous in both carriageways. The joints are skewed also at a number of locations. Instead of constructing longitudinal joints, the pavement has been allowed to crack naturally in the centre.
- Dowel and tie bars are not present for load transfer across joints.
- Compressive strength tests on 20 cores show the strength ever after one year is much less (23 to 38 MPa) than the 28-day compressive strength of 40 MPa specified for PQC in highway
- Five of eight locations have poor subgrade soil with CBR between 2 to 7%, against the requirement of minimum 8%, which is normally specified for new constructions.
- The subgrade soil is not homogenous within 1.3 km length of the stretch.
- The subgrade is not properly compacted
- The concrete slabs have been laid directly over GSB. There is no DLC layer provided.
- Since there are no longitudinal drains provided, drainage conditions are poor
- The quality of work executed at site is not meeting the specified requirement.
- The premature distress developed in the road is due to poor design and quality of construction for the traffic & weather conditions at site.
- The 1.3 km long section is a market place with shops on both sides. Also, this section is four-laned, while the remaining project length is two-laned. As a result the loading patterns is not as severe as on two lane road A well designed, constructed and maintained rigid pavement does not normally deteriorate so early.
- The above conclusions indicate that the rigid pavement in the 1.3 km stretch of Manoharpur-Dausa (design change 61+018 to 62+318) was not constructed as per standards. It lacks the strength of a typical “PQC” to cater to the loaded trucks that are predicted to use the pavement.

VII. REHABILITATION MEASURES

- Full depth repair- Depending upon the severity and extent of cracking, cross-stitching and partial/full depth repairs shall be carried out. Since the large numbers of slabs in both the carriageways are badly cracked, the choice of this option may not be practical.
- Reconstruction as flexible pavement- Break the existing pavement in to small pieces and compact with roller to seat the pieces properly. Treat this as a cemented aggregate layer and reconstruct as flexible pavement with the following crust on top (Aggregate layer: 100 mm, DBM :50 mm, BC: 50 mm)
- Reconstruction as rigid pavement- Since the subgrade is not meeting the required specification, the pavement shall be reconstructed as rigid pavement itself right from the subgrade level as follows:

Dismantle the existing concrete pavement and GSB.

Lay subgrade of minimum 8% CBR requirement as per specification and provide the crust as under:

GSB	-	150
DLC (M-10)	-	150
PQC (M-40)	-	300

These above options are not considered feasible since it will be very costly and will result in wastage of material resources

- **Overlay-**
  - **Unbonded Concrete overlay**
    Rectify the defects in the existing pavement as per IRC: SP: 83-2008. Provide separation layer of 50 mm DBM. Further provide a layer of 200 mm thick concrete of M 40 grade as wearing surface.
  - **Bituminous overlay**
    Rectify the defects in the existing pavement as per IRC: SP: 83-2008. Provide tack coat and lay bitumen impregnated geotextile to arrest reflective cracks. Provide 50 mm BC with VG 40 grade bitumen as wearing surface.

APPENDIX:

On the basis of the data provided by the study and with the help of Visual Basic Language a program was made in the Microsoft Excel which would provide the cost effective rehabilitation measures for the rigid pavement with the right input. The screenshots of the program are illustrated below

1. ***Load Transfer Efficiency Testing:*** This sheet is basically an input sheet which calculate the load transfer efficiency which is to be used in later sheets of the program. Loading on one side of the joint or crack will help to get the deflection to be used in this sheet.

Deflection on the unfolded side of the joint or crack (mils)	12
Deflection at the loaded side of the joint or crack (mils)	26
LTE	46.15384615

Figure A1: Screenshot of Load transfer efficiency test on VBA program made in Microsoft Excel

2. ***Deflection Testing:*** This sheet is also an input sheet to calculate the basin area created due to the damaged caused on the pavement.

Deflection (mils) at	0	ft from the loading position	1
Deflection (mils) at	1	ft from the loading position	2
Deflection (mils) at	2	ft from the loading position	1
Deflection (mils) at	3	ft from the loading position	2
Basin Area			54

Figure A2: Screenshot of Deflection testing on VBA program made in Microsoft Excel

3. ***Dynamic Cone Penetration Test***: This program is made to calculate the elastic modulus of the sub grade soil with the help of penetration ratio and CBR values.

Penetration Ratio (mm/blow)	10
CBR	22.15047
Elastic Modulus (lbf/in^2)	18517.62

Figure A3: Screenshot of Dynamic cone penetration test on VBA program made in Microsoft Excel

4. ***Performance Monitoring***: Here, in this program visual inspection of the pavement is done to fill the essential inputs to find out the correct procedure to monitor the pavement condition.

Pavement Type (1:PCC, 2:ACOL)	1
Pavement Age (yrs)	11
Age of Pavement Evaluation Data	1
Pumping with or without staining, missing joint seal material, or edge drop off (1:Yes, 2:No)	2

Figure A4: Screenshot of Performance monitoring on VBA program made in Microsoft Excel

5. ***Preservative Maintenance***: This program will give you the cost effective method for preservation of the pavement.

CRCP working cracks (inches)	0.04
ACOL Reflection Crack (1:Yes, 2:No)	2
Amount of Sealant Damage (%)	30
Trapped surface water in depressed areas (1:Yes, 2:No)	2
Drainage Coefficient	12
Subgrade Penetration Ratio (in/blow)	1

Figure A5: Screenshot of Preservative maintenance on VBA program made in Microsoft Excel

6. ***Functional CPR***: In this sheet, after putting all the data you will get cost effective functional CPR method for the pavement.

2" Wide Spall as % of crack/joint	20
Spall Depth (1:Deep, 2:Shallow)	2
Patches/mile	20
Faulting	0.5
Bump (1:Stable, 2:Unstable)	1
Settlement (1:Stable, 2:Unstable)	1
Badly Spalled ACOL reflection Crack (1:Yes, 2:No)	1
LTE	80
Deflection Basin Area	30
Hard Aggregate or ACOL (1:Yes, 2:No)	1

Figure A6: Screenshot of Functional CPR on VBA program made in Microsoft Excel

7. ***Structural CPR:*** Here after putting all the data you will get cost effective structural CPR method for the damaged pavement.

Longitudinal Crack (1:Yes, 2:No)	1
Shoulder Joint Separation (1:Yes, 2:No)	1
Pumping on Shoulder Joint (1:Yes, 2:No)	1
Shoulder LTE	60
% of GPR indicated voided crack/joints	30
Bumps (1:Unstable, 2:Stable)	1
Settlement (1:Unstable, 2: Stable)	1
JCP Corner Breaks (1:Yes, 2:No)	1
CRCP Punchouts	20
JCP Shattered Slab (1:Yes, 2:No)	1
CRCP Broken Cluster Area (1:Yes, 2:No)	1

Figure A7: Screenshot of Structural CPR on VBA program made in Microsoft Excel

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